Magnetic noises due to direct-current electric railcars

K. Yamazaki [1], K. Kato[1], K. Kobayashi [2], A. Haga [3], Y. Kumagai [3], and K. Fujiwara [4]

[1] *Research & Development Institute, Takenaka Corp., 270-1395 Chiba, Japan;*
[2] *Applied Superconductivity Research Lab., Tokyo Denki Univ., 270-1382 Chiba, Japan;*
[3] *Dept. of Electrical Eng., Tohokugakuin Univ., 985-8537 Miyagi, Japan;*
[4] *Dept. of Electrical Electronic and Eng., Okayama Univ., 700-8530 Okayama, Japan*

1 Introduction

Biomagnetic signals are very weak compared with those of environmental magnetic fields due to trains and motor cars. In Japan, fluctuation and frequency dependence of the environmental magnetic noises at low frequencies in urban areas are considerably different between the daytime when direct-current (dc) electric railcars are running and the nighttime when there is no traffic. In Kagoshima city, a high coefficient of correlation was observed between urban magnetic noises and an electric current for streetcars at measuring points near to the railroad and when the electric current is sufficiently large depending on the number of starting streetcars [1]. It was supposed that a main factor of the magnetic noise due to the streetcar is the unbalanced electric current between a feeder and return line, which is mainly caused by leakage currents to the ground [1]. On the other hand, the amplitude of the fluctuation of the magnetic noise (AFM) in a magnetically shielded room (MSR) for biomagnetic measurements depends on not only the environmental magnetic fields of the location but also the shielding effect of the MSR. Therefore, it is important to predict the AFM due to the dc electric railcar to select an optimal location for biomagnetic measurements and to design the shielding effect of the MSR.

In this paper, the fluctuations of magnetic fields were measured at three locations near to railroads of dc railcars at Tagajo city, Sendai city and Koto-ku in Tokyo. All railcars use personal tracks. Firstly, the fluctuation characteristics of magnetic fields from the nighttime to the daytime at three locations were discussed to understand that the electric current of the dc electric railcar nearby is the main source of the environmental magnetic field at low frequency. Secondly, the relationship between the AFM and the distance from the railroad was investigated. Thirdly, by comparing the AFM's measured as a function of the distance from the railroad with those analyzed as a function of the leakage electric current to the ground, a method of predicting AFM's due to the dc electric railcars was proposed.

2 Methods

2.1 Measurement

Figure 1 shows the measuring points of the environmental magnetic noise at three locations. The measuring points were determined according to the distance from the railroads. The selected locations and the related railroads were as follows: (a) Tagajo city - JR Senseki line, (b) Kotodai park at Sendai city - Sendai subway, (c) Minamisuna at Koto-ku in Tokyo - Tozai line (subway) of Teito rapid transit authority. The magnetic noises were measured by using a flux-gate magnetometer (Applied Physics Systems, APS520A) and were recorded in a data-recorder simultaneously. In the case of JR Senseki line, the environmental magnetic noises were measured at several points located at about 2,000m, 6,700m and 13,700m away from the railroad in addition to those as shown in Fig. 1 only during a period when the last train was running.

2.2 Analysis

The AFM was calculated as a function of the distance from the railroad by summing up the magnetic fields generated by the infinitely long straight electric currents of a feeder and return line. The calculations were carried out based on an assumption that a ratio of the electric current of the return line (I_r) to that of the feeder line (I_f: 100A) was fixed. The selected ratios were 0.98 (I_r: 98A), 0.95 (I_r: 95A), 0.9 (I_r: 90A), 0.8 (I_r: 80A), 0.7 (I_r: 70A) and 0.6 (I_r: 60A). The measured AFM's were compared with those calculated.

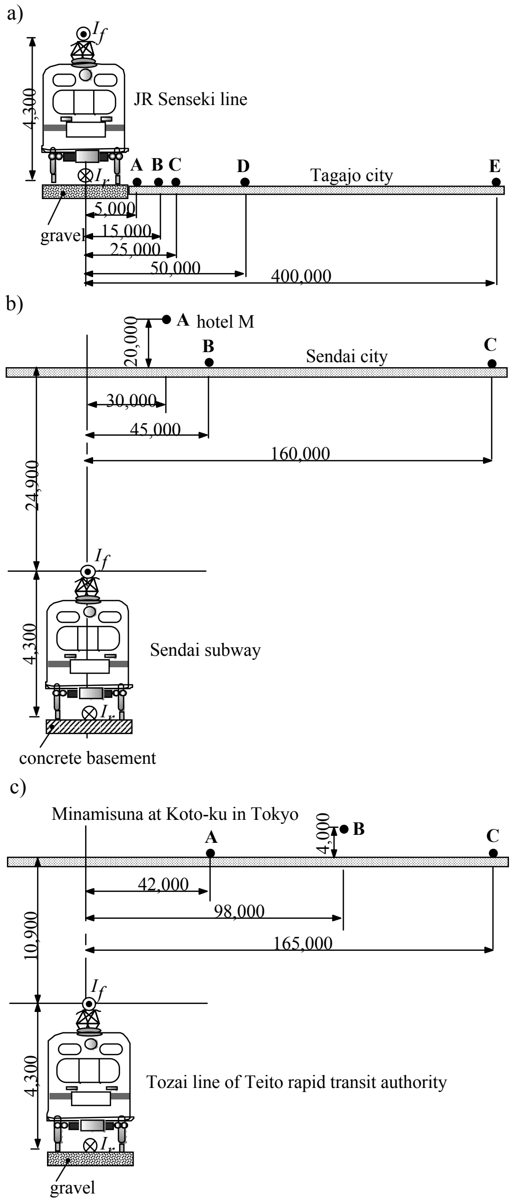

Figure 1: *Measuring points at selected locations and related railroad, a) Tagajo city - JR Senseki line, b) Sendai city - Sendai subway and c) Minamisuna at Koto-ku in Tokyo - Tozai line (subway) of Teito rapid transit authority.*

3 Results

3.1 Fluctuation of magnetic field due to dc electric railcar

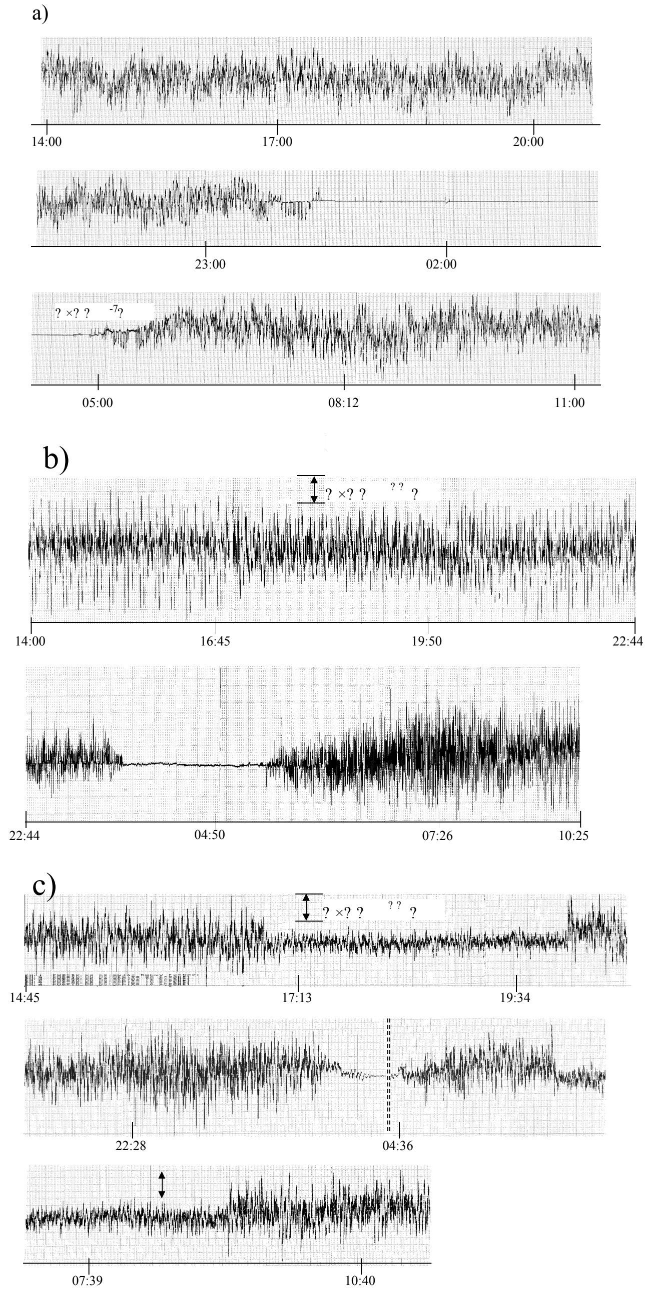

Figure. 2: *Fluctuation of magnetic field in vertical direction from daytime to daytime through night, a) point D at Tagajo city (50 m away from JR Senseki line), b) point A at Sendai city (30 m away from Sendai subway) and c) point A at Koto-ku (42 m away from Tozai line of Teito rapid transit authority.)*

Figure 2 shows the fluctuation of magnetic fields in the vertical direction at the point D (about 50 m away from JR Senseki line (a)), at the point B (about 30 m away from Sendai subway (b)) and at the point A (about 42 m away from Tozai line (c)) from the daytime to the daytime through the night. The distances to the railroads at three points are a little different from each other. A common tendency for three points is that the fluctuation of the environmental magnetic noise is considerably different between the daytime when the dc electric railcars are running and the nighttime when there is no traffic. This means that the fluctuations of the magnetic noise at these three measuring points are mainly due to the dc electric railcar. In spite of almost the same distance from the railroad to the three points, the maximum AFM's at daytime were about 1.00×10^{-6} T at Tagajo city, 2.25×10^{-7} T at Sendai city and 3×10^{-6} T at Koto-ku, respectively. The difference between them can be explained as follows: Firstly, the number of transported people by Tozai line seems to be much more than that by JR Senseki line and by Sendai subway. This corresponds to the increase of the number of trains during an hour and the number of cars composing one train of Tozai line compared with those of the other lines. Consequently, the electric current of Tozai line is much larger than those of the other lines. It results that the AFM is the highest at Koto-ku. Secondly, as shown in Fig. 1, the track of Sendai subway is laid on the concrete basement, but those of JR Senseki line and Tozai line are laid on the gravel, respectively. Therefore, the leakage resistance (*LR*) between the rail and the ground of Sendai subway is high (1260 Ωkm [2]) compared with those of JR Senseki line (10 Ωkm [3]) and Tozai line (8.5 Ωkm [4]). It results that the unbalanced electric current between the feeder line and the railroad depending on the leakage current to the ground of Sendai subway is lower than those of the other lines.

The other characteristics are as follows: the AFM at Koto-ku during the morning rush time (7:00-9:00) is smaller than that at daytime. Especially after 20:00, the AFM is the largest through the daytime, although the number of running trains is the maximum in the rush hour time. A regular cycle is also recognized in the fluctuations of the magnetic field of at Sendai city.

3.2 Relationship between amplitude of fluctuation of magnetic field and distance from railroad to measuring point

Figure 3 shows the magnetic fields in the vertical direction during a period when the first train is running (a) at the points E and F at Tagajo city (JR Senseki line) and (b) at the point B and C at Sendai city (Sendai subway). Figure 4 shows the magnetic fields in the vertical and horizontal direction at the point A, B and C at Koto-ku (Tozai line) during a period when the first train is running. Compared with the decreasing ratio of the AFM between the point C and the point B of Sendai subway (Fig. 3 (b)), that between at the point C and the point B of JR Senseki line (Fig. 4(a)) seems to be larger. On the other hand, compared with the decreasing ratio of the AFM in the vertical direction between the point C and the point A (Fig. 4 (a)) of Tozai line, that in the horizontal direction between them (Fig. 4 (b)) seems to be smaller.

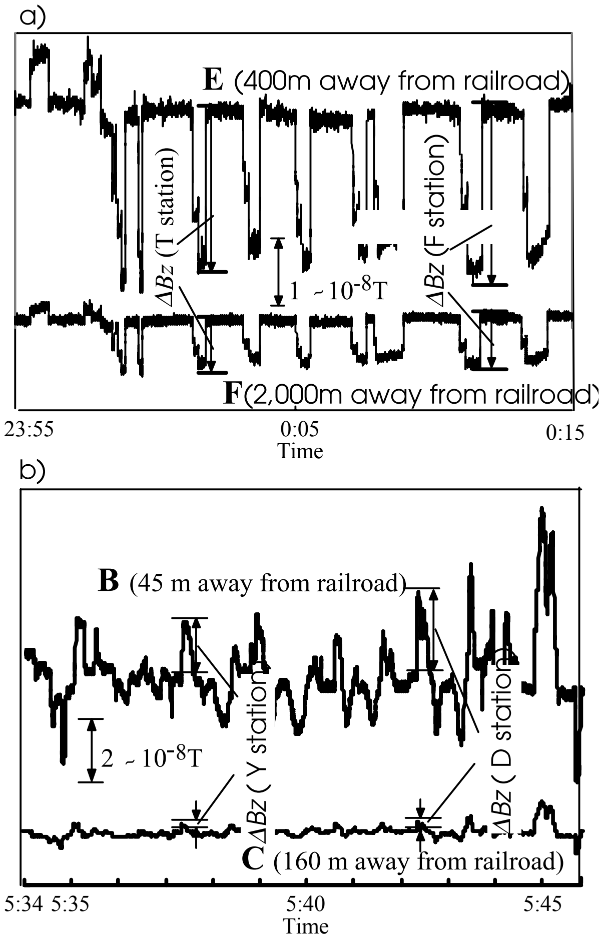

Figure 3: *Fluctuations of magnetic field in vertical direction during a period when the first train is running, a) points E and F at Tagajo city and b) points B and C at Sendai city.*

Figure 5 shows the effect of distance from the railroad to the measuring point and at three points. The relationship between the AFM ΔB_z in the vertical direction and the distance (x [m]) from the railroad to the measuring point can be expressed as

$$\Delta B_Z = a \bullet x^{-k} \qquad (1)$$

where k is the decay factor. If $I_f = -I_r$ (the electric current of the return line is equal to that of the feeder line), $k = 2$. If an infinitely long electric current is assumed, $k = 1$. The decay factor k of Sendai subway is about 1.6, and Tozai line and JR Senseki line have the same k of about 0.9. It reflects that the AFM due to Sendai subway decreases rapidly with the distance compared with those due to the other lines.

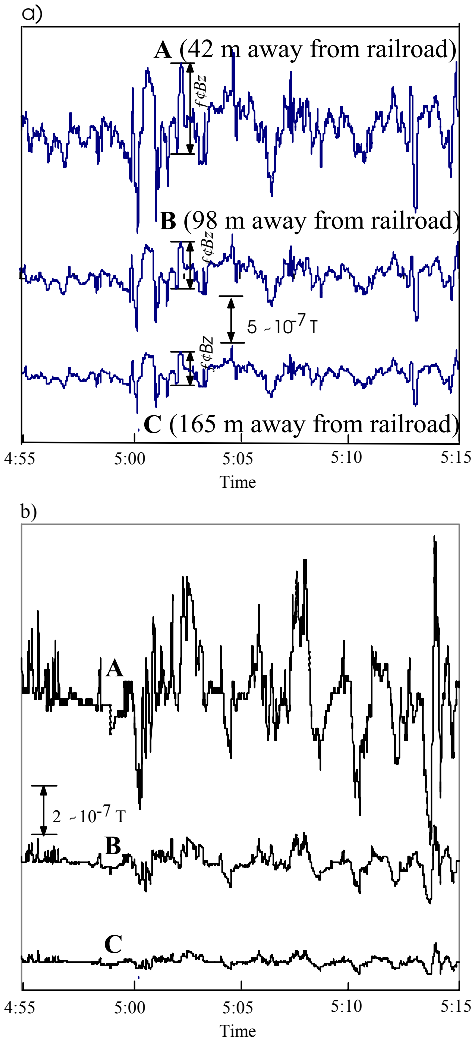

Figure 4: *Fluctuations of magnetic field in vertical and horizontal direction at Koto-ku during the first train of Tozai-line is running, a)* B_z *in vertical direction and b)* B_y *in horizontal direction.*

On the other hand, the decay factor k in the horizontal direction due to Tozai line is about 1.8 which is higher than that in the vertical direction.

4 Discussion

Figure 6 shows the distance dependence of the calculated AFM's of Sendai subway in the vertical direction. The measured AFM's are also plotted. The measured k's are fairly in good agreement with the calculated k's in the case of I_r = 80 A at JR Senseki line, and in the case of I_r = 60-80 A at Tozai line, respectively (figures are omitted). On the other hand, in the case of I_r = 98 A at Sendai subway, the measured k is fairly in good agreement with the calculated k. Therefore, it can be supposed that the decay factor reflects the unbalanced electric current (I_f - I_r) which is mainly due to the leakage electric current to the ground depending on the leakage resistance (*LR*). The *LR* of Sendai subway is in one order higher than those of the other lines. It results in the difference of the k between Sendai subway, JR Senseki line and Tozai line. Conversely speaking, the AFM due to the dc electric railcar at any distance from the railroad can be easily predicted as shown in Fig. 6, if the k is measured.

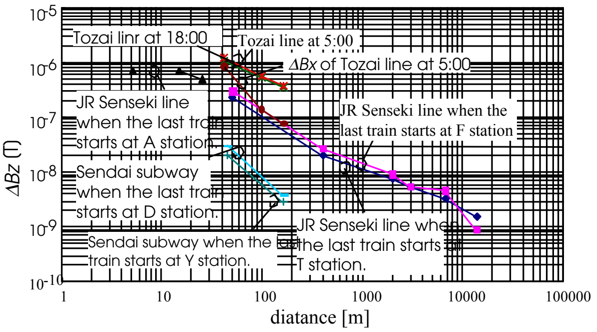

Figure 5: *Effect of distance from railroad to measuring point.*

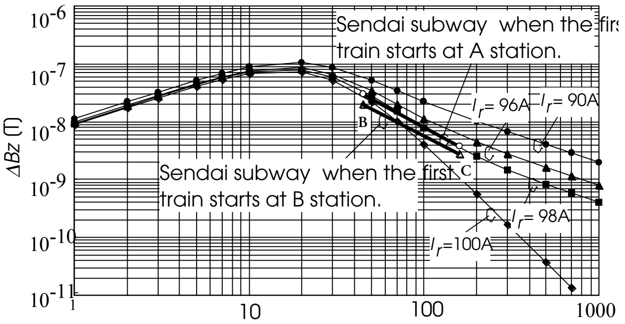

Figure 6: *Distance dependence of the maximum fluctuation of magnetic field in vertical direction of Sendai subway.*

References

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